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Investigation on Microwave Absorption property of Co^{2+} and Cr^{3+}Substituted M-type Ba-SrHexagonal Ferrite Synthesized by a Ceramic Method

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Abstract: The standard ceramic method was used to synthesized Co^{2+} and Cr^{3+} ions substituted M-type $Ba_{0.5}Sr_{0.5}Co_xCr_xFe_{12-2x}O_{19}$ hexagonal ferrites compositions where x represents doping whose value varies from 0.0 to 1.0 in steps of 0.2. Microwave absorption property of obtained ferrite composition was analyzed using "Absorber Testing Device Method" in relation to frequency (X-Band), thickness and substitution. Quarter wavelength mechanism has been used to evaluate the microwave absorption property. The calculated values for the parameters are in close agreement with the theoretical values. In doped composition, with an increase in substitution of Co^{2+} and Cr^{3+} ions, the microwave absorption is found to increase. Good microwave absorption was shown by the compositions x = 0.0 and 0.4 having the value of the absorbed power of 96.2 and 96.5 % at 11.22 and 8.2 GHz respectively. In the compositions, x = 0.0, 0.4, 0.8 and 1.0 large microwave absorption occurs due to the contribution of quarter wavelength mechanism.
Keywords: ATD Method; Hexagonal ferrites; Absorbed Power; Microwave absorption.

1. Introduction

With the advancement in information technology, number and types of wireless devices have shown an exponential rise, which is the basic cause of electromagnetic pollution. This pollution, in turn, produces electromagnetic interference which affects the functioning of these electronic devices badly. It has adverse effects on the biological system also. This problem can be solved by microwave absorbers also known as EMI suppressors which have the capacity to attenuate the high frequency signals thus reducing EMI.

Microwave absorbers are prepared using ferrites as their basic component. Various electrical, electronic and wireless devices e.g channel filters, gyromagnetic devices, antenna, wideband transformers, and radar absorbing materials (RAM) etc. incorporates ferrites [1-4]. Ferrites have better dielectric and magnetic properties than conventional dielectric materials due to which they act as better EMI suppressers.

Ferromagnetic properties such as domain wall resonance, ferromagnetic resonance and large dielectric and magnetic lossesare shown by M-type hexaferrite due to which it absorbers microwave radiations and leads to EMI reduction [5-10]. M-type doped hexagonal ferrite'smicrowave absorption properties have been studied by various researchers

This paper concerns with Co^{2+} and Cr^{3+} ions substituted M-type $Ba_{0.5}Sr_{0.5}Co_xCr_xFe_{12-2x}O_{19}$ hexagonal ferrites compositions where x represents doping, whose value varies from 0.0 to 1.0 in steps of 0.2, prepared by the standard ceramic method. This paper elucidates the role of quarter wavelength mechanism in the process of absorption.

2. Experimental method

Standard ceramic method [11] was used to synthesized the hexagonal ferrites (M-type) with composition $Ba_{0.5}Sr_{0.5}Co_xCr_xFe_{12-2x}O_{19}$ (x = 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0).

The starting material used were AR grade of Strontium carbonate ($SrCO_3$, 99.99% pure**,** Sigma-Aldrich**),** Cobalt carbonate ($CoCO_3$, 99.99 % pure, Sigma-Aldrich), Bariumcarbonate ($BaCO_3$,99.98 % pure, Merck, Germany),Ferric oxide (Fe_2O_3, 99.99% pure, Merck, Germany) and Chromium oxide (Cr_2O_3, 99.99 % pure, Sigma-Aldrich).

The chemical reagents in stoichio metric amount were ground with distilled water for the time interval of 8 hours with the help of an agate pestle and mortar. Pre-sintering was done at the temperature of 1000 °C in an electric furnace. This process continues for 10 hours and room temperature was obtained by cooling slowly at the rate of (5 ºC/ min). Re-grounding was done again. It was followed by the process of sieving using sieves containing mesh sized 220 B.S.S. pressing of the product was done at a uniaxial pressure of 75 KN/m^2using the hydraulic press to obtained pellets. These pellets were sintered at a temperature of 1150 °C for 15 hours for final sintering by maintaining the heating and cooling rates at ± 5 °C/ min.

Absorber Testing Device (ATD) method [12-13] was used to analyze the microwave characteristics of $Ba_{0.5}Sr_{0.5}Co_xCr_xFe_{12-2x}O_{19}$ (x = 0.0 to 1.0) ferrites at X-band in relation to thickness, frequency and substitution.

Frequency Synthesizer, HP Model 83751AgenerateX-band frequencies ranging from 8 to 12 GHz in the rectangular waveguide havinginternal dimensions given as:l=22.86 millimeter, b=10.16 millimeter where l and b represent length and breadth respectively. Isolator permits the unabsorbedmicrowave to propagate in one specific direction and blocks in opposite direction. The directional coupler has three ports:the first one was primary inputwhile second and third were the secondaryoutput ports. The ferrite sample backed metal plate was attached at the output 1 of the secondary port. The reflected microwave signal from the ferrite sample was calculated by using power meter attached to secondary output port 2. Different signals were measured by the "Microwave Power Meter" and the reflected power measured at output port 2 was used for calculation of parameter $S_{11.}$

We know that the reflection loss (RL) is given by the expression:

$$RL\ (dB) = 20 \log_{10}(|S_{11}|) \quad (1)$$

-10 dB reflection loss exhibits 90% microwave absorbed power. Higher reflection loss leads to greatermicrowave absorption and vice versa.

The calculations of reflected power (%) can bedone as:

$$\text{Reflected Power } (\%) = (P_r/P_{rw}) \times 100 \quad (2)$$

Where P_r= Thereflected power from the samplewiththe metal plate.

P_{rw}= Thereflected power from themetal plate without the sample.

Calculated absorbed power is found as:

$$\text{Percentage of Absorbed Power} = 100 - \text{Percentage of Reflected Power} \quad (3)$$

3. Results and discussion

3.1Microwave absorbed power

Figure 1 depictsThe variation of absorbed power (P_{ab}) as a function of substitution of Co^{2+} and Cr^{3+} cations and frequency in $Ba_{0.5}Sr_{0.5}Co_xCr_xFe_{12-2x}O_{19}$ hexagonal ferrites. The highervalue of absorbed power P_{ab} isreported in substituted compositionx = 0.4 and in undoped composition x=0.0in the frequency range taken for investigation.All the compositions show absorbed power larger than 93% in various frequency regions.

x = 0.2 and 0.6compositions show maximum & minimum P_{ab} values of 96.2 and 93.8 % at 8.2GHz and 9.88 GHzrespectively.

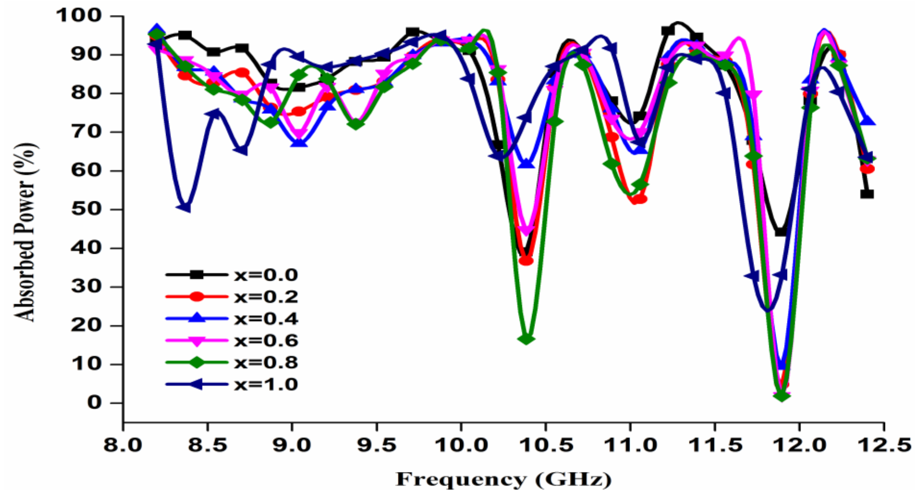

Figure 1. Curves of Absorbed Power vs. Frequency and Substitution of Co-Cr ions in$Ba_{0.5}Sr_{0.5}Co_xCr_xFe_{12-2x}O_{19}$ hexagonal ferrites (x varies from 0.0 to 1.0 in steps of 0.2).

Table 1 represents different parameters corresponding to maximal absorbed power, -10 dB bandwidth and quarter wavelength mechanism. Table 1 shows the maximal absorbed power ($P_{abmax.}$) measured atrespective matching frequency "f_{mat}" in $Ba_{0.5}Sr_{0.5}Co_xCr_xFe_{12-2x}O_{19}$ (x varies from 0.0 to 1.0 in steps of 0.2)ferrites. In substituted composition, $P_{abmax.}$ value rose with the increase in doping of Cr^{3+} and Co^{2+}ions. Compositions x = 0.0, 0.4 and 0.8 reportedmore absorbed power, at 11.22, 8.2 and 8.2 GHz and while composition x = 0.2, 0.6 and 1.0have comparatively lower value of $P_{abmax.}$ at 8.2, 9.88 and 9.88 GHz respectively.

Table 1

Maximum absorber power (P_{amax}%),Matching Frequency (f_{mat}), Calculated thickness, Frequency band and Bandwidth for Reflection Loss greater than -10 dB in $Ba_{0.5}Sr_{0.5}Co_xCr_xFe_{12-2x}O_{19}$ ferrites.

Composition x	P_{abmax} (%)	Matching Frequency (f_{mat}) (GHz)	Thickness t=λ/4 (mm) (calculated)	Frequency band RL > - 10dB (GHz)	Bandwidth (MHz)
x=0.0	96.2	11.22	3.0	9.54 - 10.04	500
x=0.2	94.9	8.2	2.0	9.71 - 10.04	330
x=0.4	96.5	8.2	2.5	11.22 – 11.56	340
x=0.6	93.8	9.88	1.7	9.71 – 10.21	500
x=0.8	95.3	8.2	2.1	9.71 – 10.04	330
x=1.0	95.0	9.88	2.4	9.54 – 10.04	500

3.3 Quarter Wavelength Mechanism

Quarter Wavelength Mechanism states that if the ferrite material's thickness is equivalent to the quarter wavelength of incoming signal then it will be fully absorbed on propagating through it [14- 17].

The signal on propagating through ferrite sample with metal plate back gets split into two parts. The first part suffers partial reflection from the front surface of the material and the second part which transmits through the material is reflected by the metal plate. Both the parts rejoins at the front surface but as both of them are 180° out of phase with each other hence nullify one another and hence resulted in total reflection become zero.

This condition is shown mathematically as

$$t_m = \frac{n\lambda_0}{4} \qquad \text{Where } n = 1, 3, \ldots 5\ldots\ldots\text{etc.} \tag{4}$$

$$\lambda_0 = \frac{\lambda}{\sqrt{\mu\varepsilon}} \tag{5}$$

Where t_m=thicknesswhich has been calculated or obtained theoretically
λ_0=wavelength of the signal propagating in a material
λ=wavelength of signal promulgating in air
μ= complex permeability of the material
ε=complex permittivity of the material
Derivations for μ and ε from S-parameters are done by using Nicholson-Ross method [18].
Table 1showsan application of quarter wavelength mechanism for differently prepared samplescorresponding tothe calculated or theoretical thickness ($t_{cal} = n\lambda_o/4$). x = 0.4 has shown maximum absorbed power of 96.5 % among all compositions. Specifically, compositions x = 0.0, 0.8 and 1.0have more contribution tothe quarter wavelength mechanism.
The table shows the compositions x = 0.0and 1.0 have500 MHz absorption bandwidth (ABW) at the similar frequency band from 9.54 GHz to 10.04 GHzand x=0.6 has similar absorption bandwidth at 9.71 to 10.21 GHz. whereascompositions x = 0.2 and 0.8 have ABW of 330MHz at the same frequency band from 9.71 to 10.04GHz.Composition x = 0.4 has 340 MHz (ABW) from 11.22GHz to11.56 GHz.

4. Conclusions

$Ba_{0.5}Sr_{0.5}Co_xCr_xFe_{12-2x}O_{19}$ (x varies from 0.0 to 1.0)hexagonal ferrite samples have been preparedwith the help of standard ceramic method.In substituted compositions, it was found that the microwave absorption property enhanced with doping of Cr^{3+} andCo^{2+}cations in synthesized hexagonal ferrites (M-type).The quarter wavelength mechanism wasused to explorefrequency and thickness for highest absorption and for designingabsorbers at the microwave frequency.Microwave absorption property analysis suggested that compositions x = 0.0, 0.4, 0.8 and 1.0have the largercontribution of quarter wavelength mechanism for large microwave absorption.Composition x = 0.4 showsmicrowave absorberor Electromagnetic interference reduction characteristics with 96.5% absorbed power at matching frequency and thickness of 8.2 GHz and 2.7 mm respectively.The observed absorptionbandwidth in compositions x = 0.0, 0.6 and 1.0 is found to be 500 MHz while for x = 0.2 and 0.8compositions its value comes out to be 330 MHzat -10 dB.Microwave absorber or EMI suppressorscan be seen as a potential application of synthesized hexagonal ferrite compositions

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